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Analysis on energy intensive industries under Taiwan's climate change policy

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ABSTRACT

This study addresses the planning and implementation of energy, industry, and carbon economy policies concerning the development of the Taiwan's energy intensive industries from perspective of climate change. As a newly industrialized country, Taiwan attaches greater importance to the development of green energy and low-carbon industries, in cooperation with global pressure for carbon reduction due to climate changes, through energy and industrial conferences. Thus, in the past year the Taiwanese government constructed four laws concerning energy and carbon reduction in order to drive the green energy industry; furthermore, it plans to reduce current carbon emission benchmarks. Nevertheless, statistical analysis found that in the last decade, energy intensive industries have presented structural unbalance regarding energy consumption, CO_2 emissions, energy intensity, contributions to the GDP, and product value. Industries in the industrial sector have high energy consumption, high carbon emissions, and increase total domestic consumption and carbon emissions, which have disproportionate contributions to industrial added value; nevertheless, the government continues to approve investments for such energy intensive industries, and results in continuous increases in energy consumption and carbon emissions. This contradictory phenomenon indicates that newly industrialized countries rely on a manufacturing economic structure, which is difficult to adjust and violates the trends of a global low-carbon economy. Hence, the government must examine and adjust such unbalanced industrial structures, where such adjustments are executed in a fair and just manner, and encourage the development of high value-added measures for low-carbon manufacturing and service sectors to become equal with competitors in a global economy.

Contents

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1. Introduction

Climate change issues have posed challenges to energy and industrial policies of all countries, in particular, newly industrialized countries (NICs), which rely on foreign trade with high energy dependence since the Kyoto Protocol entered into force on February 16, 2005. Under Kyoto Protocol, Annex I, countries (developed countries) of UNFCCC agreed to cut their collective greenhouse gas emissions by an average of 5.2% of the 1990 level, conducted over the 5-year period between 2008 and 2012, based on the principle of “common but differentiated responsibilities.” However, the post Kyoto protocol regime requires newly industrialized countries (NICs) to assume added responsibilities in order to reduce and limit greenhouse gas emissions after 2012 [1–6]. The UN Climate Change Conference in Durban (COP17) concluded with the adoption of the “Durban Platform”, a set of decisions that lay the ground for adopting a legal agreement on climate change no later than 2015. That indicates, the NICs will face more pressure of carbon reduction from international commitment and legal framework.

Taiwan’s government has responded to international greenhouse gas emission reductions since 1998, and has vigorously promoted carbon reduction policies in recent years; however, greenhouse gas emissions have increased in the past 20 years due to economic and political pressures of industrial development [7]. In the face of future sanction pressures from the international green convention, Taiwan is in a crucial transition period of sustainable development of economy and society, involving national energy policies, energy conservation, carbon reduction planning, and industrial policies adjustments. In particular, the newly industrialized countries that rely on high energy intensity, foreign trade, and manufacturing must learn transition issues of a low-carbon economy and society.

The remainder of this paper is organized as follows. Section 2 reviews Taiwan’s energy consumption structure, national carbon emission structure, and related issues, and in particular, points out the carbon emission problems of the industrial sector and the greatest energy consumption industries (energy intensive industries). Section 3 introduces the policy orientation of the Taiwanese government for adaptation to climate changes, including energy policies, energy laws, industrial policies, carbon reduction policies, and implementation measures. Section 4 defines energy intensive industries and discusses year by year their percentile in total energy consumption, contribution percentile to the GDP; as well as comparing their energy consumption with contributions to GDP, which presents a highly unbalanced relationship. Section 5 analyzes downstream manufacturer’s (created by upstream energy intensive industries of the industrial sector) contributions to product value, and further compares the unbalance between individual industry output value and their corresponding CO_2 emission rate. Through conflict between actual industry policies and carbon reduction plans for climate change, this section indicates that, Taiwan’s industrial policies should be oriented toward a sustainable and low carbon economy. Section 6 offers the conclusions of this study.

2. Energy consumption and carbon emission structure

2.1. Energy consumption and industrial development

Due to a lack of natural resources, Taiwan has high energy dependence, and in the past two decades, more than 99% of consumed energy was imported from other countries. With economic growth, imported energy is continuously increased. In the most recent five years, imported energy has exceeded 198,642 10^3KLOE, reaching the highest consumption point in Taiwan’s history. As a newly industrialized country, Taiwan relies on the development of export-oriented manufacturing to drive economic growth, and in the face of slow expansion of domestic and renewable energy, most imported energy is fossil fuel based; hence, economic and social development cause increased greenhouse gas emissions. As seen in Fig. 1, the energy consumption of high energy and industrial sectors, which sustain Taiwan’s economic growth, have exceeded 50% in the most recent 20 years. This economic development mode places focus on the demands of manufacturing to consume large amounts of energy. Hence, an national industrial structural adjustment is imperative under the pressure of global carbon reduction.

Greenhouse gas emissions of CO_2, from energy fuel in Taiwan, was increased from 110 million tons in 1990 to 262 million tons in 2007, but was reduced to 239 million tons in 2009, which was due to the global economic depression. In the past 20 years, CO_2 emissions have increased from 116% to 137%, for an annual increase rate of 4.9%. Meanwhile, CO_2 emissions in Taiwan were 252 million tons in 2008, accounting for 1% of the global emission rate, and ranked 22nd on the global list. Correspondingly, CO_2 per capita emission was 5.5 tons in 1990 was increased to 11 tons in 2008, for the emission per capita ranking of 18th on the global list (Fig. 2).

From the cumulative trend diagram of sectors between 1990 and 2009 (Fig. 3), the industrial sector is the largest source of CO_2 emission, with its CO_2 emissions reaching 125.375 million tons in 2007, comprising 47.7% of the total emissions of 262.787 million tons; and reaching 11.546 million tons in 2009, comprising 46.1% of the total emissions of 239.615 million tons. Upon further analysis, the CO_2 emission of the industrial sector began to increase in 1996, and increased by 28.005 million tons during the period of

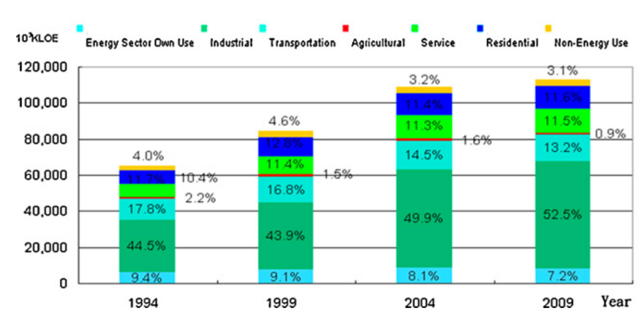


Fig. 1. Structure of total domestic energy consumption (by sector). Data source: [8].

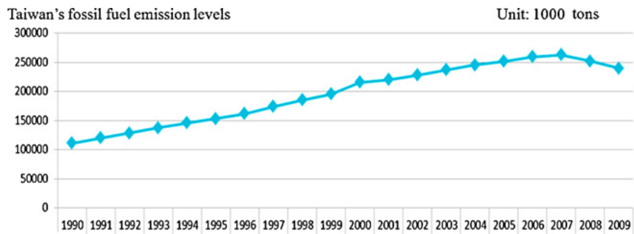


Fig. 2. Taiwan 1990–2009 fossil fuel CO_2 emission trend.
Data source: [8]. Compiled by this study.

1996–2000, 14.235 million tons during the period of 2000–2004, and 12.141 million tons during the period of 2004–2007. Moreover, the industrial sector also leads to rapid increases in total domestic CO_2 emissions.

2.2. *Main carbon emission structure of the industrial sector*

Corresponding to the above analysis, between 1997 and 2000 the total domestic emission rate increased by 41.464 million tons, of which the industrial sector accounted for 51%; during the period of 2000–2004, total domestic emissions increased by 29.815 million tons, of which the industrial sector accounted for 47.4%; and between 2004 and 2007, it increased by 17.484 million tons, of which the industrial sector accounted for 69.4%. It can be readily seen that the industrial sector is the main source driving increased CO_2 emissions in Taiwan.

In further analysis of emissions of the internal industries of the industrial sector, emissions of the paper industry, cement industry, textile industry, and electrical machine industry increased slowly with economic growth. The basic metal industry witnessed largest emissions growth between 1996 and 2000, when it increased by 7.476 million tons, and by 2.801 million tons between 2000 and 2007. The most exceptional situation is found in the chemical industry (chemical materials industry, chemical products industry, and plastic products industry), which saw CO_2 emissions increased by 9.821 million tons between 1997 and 2000, accounting for 46.5% of the emissions in the industrial sector during the same period; the chemical industry increased by 7.287 million tons between 2000 and 2004, comprising 24.4% of the emissions in the industrial sector during the same period; the chemical industry increased by 7.261 million tons between 2004 and 2007, comprising 41.5% of the emissions in the industrial sector during the same period. It can be seen that main driving forces for the increase in CO_2 emissions of the industrial sector are the basic metal industry and the chemical industry, as seen in the Cumulative Emission Trend Diagram of Main Industries (Fig. 4). Both emissions sources display rapid increases from 1997 onward; in particular, the rapid increase in emissions of the chemical industry is obvious.

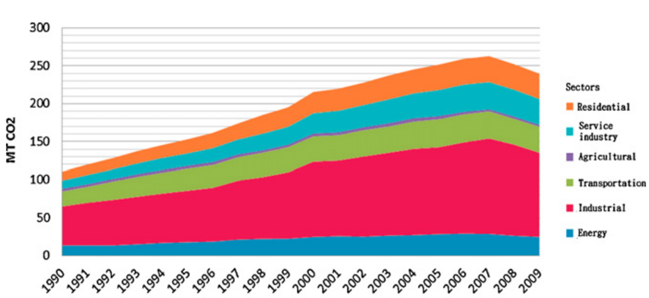


Fig. 3. Cumulative emissions trend diagram of various sectors from 1990 to 2009.
Data source: [8]. Compiled by this study.

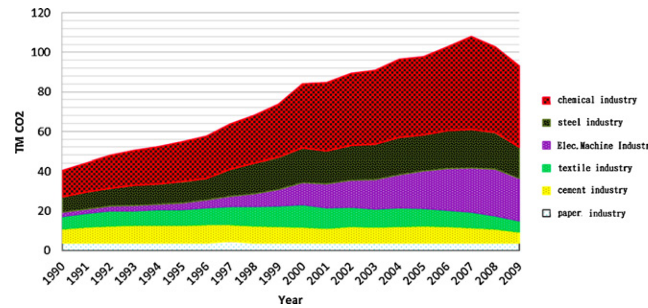


Fig. 4. Cumulative emission trend diagram of various main industries of 1990–2009.
Data source: [8]. Compiled by this study.

2.3. *Carbon emission structure of the main energy consuming industries*

As seen in Table 1, the paper industry, manufactured fibers industry, cement industry, textiles mills industry, electric machine industry, basic metal industry, and petrochemical industry (chemical materials industry) are the seven largest energy-consuming industries in Taiwan. From the percentage analysis below, it can be seen that the yearly emission of the seven energy-consuming industries comprised high percentages of emissions in the industrial sector from 1990 to 2009. For example, such emission origins comprised more than 83.3% of the total industrial sector emissions in 2008. Moreover, they separately comprised certain percentages of CO_2 emissions by the industrial sector, in particular, the basic metal industry and petrochemical industry. Based on the above analysis, except for the basic metal industry, which increased by 7.476 million tons from 1996 to 2000, and by 2.801 million tons from 2000 to 2007, the petrochemical industry is the main source driving increased CO_2 emissions, which increased by 7.049 million tons from 1997 to 2000, comprising 71.8% of the chemical industry increment; the CO_2 emission of the petrochemical industry increased by 5.744 million tons from 2000 to 2004,comprising 78.8% of the chemical industry increment; the petrochemical industry from 2004 to 2007 increased by 6.648 million tons, accounting for 91.6% of the chemical industrial increment. The cumulative emission trends diagram for 1990 to 2009 (Fig. 5) shows that these energy-consuming industries can drive the incremental curve of the total domestic CO_2 emissions, and such a change range has absolute influence that results in the same increased and decreased rates of total emissions.

2.3.1. *Summary*

According to the analytical trends mentioned in this section, the industrial sector is the main source driving CO_2 emissions in Taiwan in the recent 20 years. Differing from the paper industry, cement

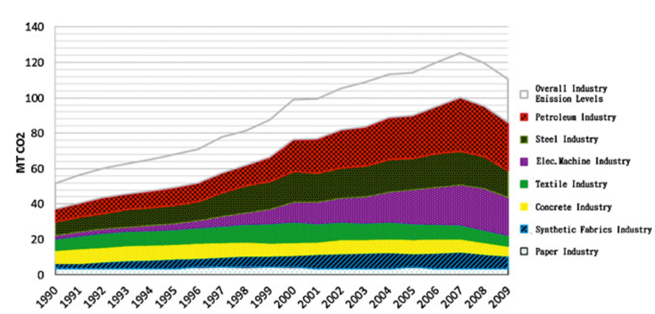


Fig. 5. 1990–2009 cumulative emissions trend diagram of the Taiwan's seven main energy consumption industries.
Data source: [8]. Compiled by this study.

Table 1
1990–2009 the CO_2 emission situation in Taiwan's 7 main energy consumption industries. Unit: million tons.

	Paper industry	Synthetic fiber	Concrete industry	Textile	Electrical	Steel	Petroleum	Industry	Total domestic emission levels
1990	3.566	2.933	7.516	6.247	1.952	7.807	7.125	51.607	110.851
1991	3.925	3.063	8.028	6.899	2.197	8.647	7.614	56.317	119.943
1992	4.063	3.267	8.51	7.508	2.351	8.974	8.942	60.099	128.22
1993	3.95	4.035	8.928	7.403	2.619	10.043	8.674	62.771	137.626
1994	4.118	4.326	8.823	7.686	2.858	10.162	9.334	65.15	145.669
1995	4.248	4.673	8.608	7.867	3.434	10.616	9.869	68.006	153.176
1996	4.428	4.924	8.679	8.473	4.054	10.848	10.494	70.994	161.624
1997	4.65	5.41	8.398	9.154	5.199	13.801	10.91	77.857	174.024
1998	4.427	6.202	8.173	9.701	6.293	15.562	11.509	81.408	185.403
1999	4.505	6.016	7.578	10.562	8.261	15.998	13.476	87.513	195.384
2000	4.476	6.678	7.474	11.166	11.141	17.549	17.959	98.999	215.488
2001	4.226	7.298	7.186	10.211	12.112	16.521	19.298	99.42	219.855
2002	4.169	7.735	8.149	9.706	13.639	17.324	21.192	105.337	227.836
2003	4.234	8.11	7.717	9.17	14.82	17.595	21.888	108.805	237.213
2004	4.42	8.175	7.772	9.53	16.668	18.581	23.703	113.234	245.303
2005	4.455	7.591	8.163	8.725	18.997	17.868	24.152	114.194	251.699
2006	4.335	8.07	8.002	8.026	20.988	19.234	26.412	120.014	259.265
2007	4.299	8.682	7.428	7.66	22.569	19.184	30.351	125.375	262.787
2008	3.96	7.604	6.894	6.691	23.526	18.351	28.259	119.664	252.042
2009	3.623	7.036	5.774	5.632	21.518	15.485	27.029	110.546	239.615

Source: [8]. Compiled by this study.

industry, textiles mills industry, and electrical machine industry, the basic metal industry and chemical industry produce the largest contribution to emission sources of the entire industrial sector; with an incremental speed of the two industries being higher than the other energy intensive industries during the three periods of 1997 to 2000, 2000 to 2004, and 2004 to 2007. The incremental speed of CO_2 emissions of the petrochemical industry (chemical materials industry) dominated CO_2 emissions in the chemical industry, resulting in quick emission growth of the industrial sector and then increased domestic emissions. Taiwan's industrial manufacturing policies have been focused on the basic metal and petrochemical industries for the past 10 years, where such energy consumption structures using fossil fuels are responsible for the unbalance phenomenon of greenhouse gas emissions.

3. Climate change polices: energy policies, energy laws, industry polices, and carbon reduction policies

Taiwan's climate change policies have involved important energy policies, energy laws, industry policies, and carbon reduction policies in the recent 10 years, which represent efforts of different phases. It can be expected that the goals of policies will be accomplished through different policy instruments and law constructs; meanwhile energy independence, efficiency, industrial adjustments, and low-carbon economy development orientation will be resulted. The important energy, industrial, and carbon reduction conferences during different periods are compiled into laws and practical orientation for policy goals (Table 2). The staged conferences, laws, and policy goals have high correlation and are analyzed as follows.

3.1. Energy policy and law construction

As a newly industrialized country, which is oriented toward manufacturing and export trade, Taiwan actively responds to the Kyoto Protocol and intends to adjust energy policies and construct relevant energy acts in order to gradually reduce energy dependence, high fossil fuel consumption, and carbon emission structures [9,10]. The domestic energy conferences, held in 1998, 2005, and 2009, and their policy goals were focused on increasing energy independence, improving utilization efficiency and reduction of industrial intensity, the development of new sustainable energy sources, the creation of carbon reduction technologies and renewable energy, rationalization of energy prices, and setting CO_2 emission reduction benchmarks [11–13]. The national energy conference, held in 2005, suggested that energy efficiency should be increased by 2% annually. It further promoted revisions to the Energy Management Act in 2009, which stipulates products shall be marked with energy efficiency labels. This conference also initiated research into a green energy industry and prepared the Renewable Energy Development Act in order to encourage development of new, renewable, and sustainable energy industries [14].

In 2008, the Executive Yuan passed the sustainable energy policy guidelines in order to construct important milestones for energy safety, economic development, and environmental protection in Taiwan. The energy consumption and industrial development principles of high efficiency, high value (two highs), and low emissions, low dependency (two lows) have become the guidelines for Taiwan to pursue a low carbon economy and society [15]. In this context, revisions of the Energy Management Act (to effectively promote energy conservation), implementation of Renewable Energy Development Act (to develop clean energy), discussion of Green House Gas (GHG) Reduction Act draft (to foster greenhouse gas emission capabilities), and the study of the Energy Tax Act (reflect external cost of energy) are conducted, as these are four important acts concerning carbon reduction. The two former acts were adopted in June 2009 [16].

3.2. Industry policy

In light of the domestic energy conference, which aimed at the reduction of energy intensity, development of renewable energy, and new energy planning by the Taiwanese government convened the sustainable economic development conference in 2006 and the meeting of industry technologies strategies in 2007. It drew up a new industrial pilot plan in 2009, initiated the Dawning Green Energy Industry Program in 2009, implemented a national energy plan, and held a national industry conference in 2010. This important policy aims to examine energy intensive industrial policies, discourage development of industries with high energy consumption and carbon emissions, increase the percentage of renewable energy in power generation, push green energy industries for a low carbon economy with new and renewable energy research plans; for example, solar photovoltaics, LED, hydrogen,

Table 2
Process of Taiwan's important polices and acts for climate change.

	Key meetings	Key legislation construction	Policy aims
Energy policy	• 1998 national energy conference	• 2009 energy management law reforms	• Increase energy self sufficiency
	• 2005 national energy conference	• 2009 renewable energy development act	• Increase energy efficiency: energy efficiency mark
	• 2008 sustainable energy policy guideline		• Decrease the concentration of energy
	• 2009 national energy conference		• Develop new energy and CO_2 reduction skills on Carbon emission standards
			• Develop renewable energy
			• Rationalization of energy prices
			• Energy saving carbon reducing goals
Industry policy	• 2006 Taiwan sustainable economic development conference	• 2009 industry innovation act	• Low carbon economic aims
	• 2007 industrial S&T policy conference		• Adjustments in energy concentration industry policy
	• 2009 new energy industry flagship plan		• Improving renewable energy ratio
	• 2009 green energy sunrise plan		• Green industry policy
	• National energy plan		• Green industry: PV, wind power, LED
	• 2010 national industry conference		• Green service industry
			• Energy concentration policy
			• Environmental assessment
			• Strengthen new energy research
			• Halt applications for investments in high energy consumption industries
Carbon reduction policy	• 2010 energy saving carbon reduction promoting meeting	• 2009 GHG reduction act draft	• Set standards for CO_2 emission
	• 2010 national energy saving carbon reduction plan	• 2009 energy tax act draft	• 2010 IPCC reduce CO_2 emissions by
			• 30% by 2020
			• GHG energy efficiency standard
			• 10 major energy saving and carbon reducing projects
			• 2007 greenhouse gas registration platform
			• Leading industry in GHG inventory and registration
			• Build a clean development mechanism
			• (CDM)
			• Set up a cap and trade platform

Source: The author.

and wind energy are the new energy industries supported by the Ministry of Economic Affairs. Such measures can assist with global green energy economy trends and construct Taiwan's low carbon economy [17].

The latest national industry conference was held in October 2010 and planned to adjust Taiwan's energy intensive industry, develop both green services industries and green industries, and suggest applications for stopping energy-consuming industrial investment plans [18]. With reference to the orientation of policies, in addition to the adoption of the Renewable Energy Development Act, the Industry Innovation Act was passed in 2009; where green industry policy incentives, preferential land tax measures, and relevant encouragement measures were taken.

The policy orientation of industry with low-carbon and high value means to adjust past industrial structures; however, the current emissions of the existing high energy-consuming industry pose a challenge according to the above analysis. In Taiwan's manufacturing, the direct and indirect CO_2 emissions are 2:3. Coal is mainly used in power generation, thus, CO_2 emissions in power generation have a high coefficient, and is equal to the 0.429 kg CO_2 equiv./degree in Japan, and 0.418 kg CO_2 equiv./degree in South Korea. CO_2 emissions in Taiwan are 0.632, 0.638, 0.637, 0.636, and 0.623 kg equiv./degree [18]. Thus, low carbon adjustment of energy and industrial structures is an important industrial policy.

3.3. Carbon reduction policy

Due to Taiwan's high dependence on fossil fuel consumption, carbon reduction is related to energy and industrial policies, which can be divided into four aspects (1) CO_2 emission reduction benchmark setting; (2) review of industry and energy intensity; (3) promotion of energy conservation and carbon reduction; and (4) capability of establishing a greenhouse gas emission reduction system. The national energy conference in 1998 specified the CO_2 emissions goal, which sets CO_2 emissions for 2020 to be reduced to the 2000 benchmark level (1998 proposal); 2008 sustainable energy policy guidelines further prepared CO_2 emission goals (2008 proposal), which is abided by the national energy conference in 2009, and the committee on energy conservation and carbon reduction of the Executive Yuan in 2010 (2010 proposal). These goals aim to reduce CO_2 emissions between 2016 and 2020 to the emissions level of 2008, and CO_2 emissions in 2020 to emissions level of 2005, and the emissions of 2025 to the 214 million tons of 2000 (Fig. 6) [19].

In regard to adjustments of industrial and energy intensity, the committee on energy conservation and carbon reduction determined a blueprint for a low carbon economy and society in May 2010, which specified that energy efficiency be increased by more than 2%, the energy intensity of 2015 be reduced by 20%, as

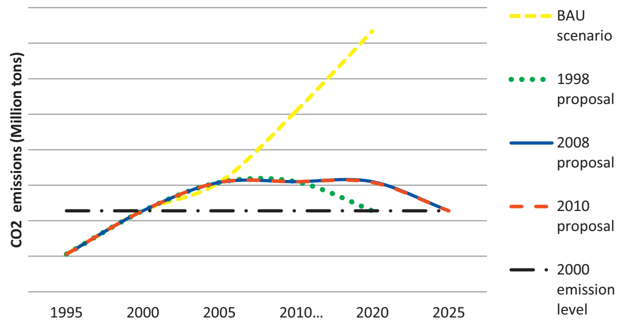


Fig. 6. Estimation of emission reductions under three proposals.
Data source: The author.

compared to 2005, and reduced by 50% by 2025. The overall energy conservation and carbon reduction plan of 2010 involves energy, residential housing, industry, transport, buildings, research, public works, education, and the construction of laws, with carbon reduction measures spreading to throughout social departments economically and socially.

To meet the above policy goals and construct the GHG reduction system capability, Taiwan's government has actively prepared the Green House Gas Reduction Act (draft) and the Energy Tax Act (draft), as well as formulating GHG energy efficiency standards, direct and indirect specifications, encouraging industrial carbon reduction, and developing low carbon technologies and national economy. Meanwhile, the EPA established a greenhouse gas registration platform in 2007 and a carbon trade platform at end of 2010, which actively assists industries to conduct inventories and voluntarily register carbon emissions and emissions reduction measures. The platforms can be used as mechanisms for integration with the international carbon Cap and Trade.

3.4. Summary

In fact, the above policies of climate changes reflects that Taiwan's government actively and carefully gives response to international carbon reduction requirements and gradually plans and develops green energy industries and national economy in order to achieve winning scenarios for energy, industry, environment, and society. The new government promised IPCC in June 2010 that carbon emissions would be reduced by more than 30; however, the policy goals will face severe challenge after further analysis of energy consumption and the carbon emission structure of energy intensive industries.

4. Energy intensive industry analysis

4.1. Energy consumption

In response to observations of the energy consuming industries that dominate total domestic CO_2 emissions, analysis was conducted on energy consumption, energy intensity, and contributions to the domestic GDP. According to the definition of the Bureau of Energy [8], energy intensive industries include the paper industry, cement industry, basic metal industry (steel industry), and chemical materials industry (petrochemical industry). The latter two industries are worthy of further discussion. The steel industry and chemical materials industry have driven increased CO_2 emissions since 1997, and CO_2 emissions accumulated between 2000 and 2007, suggesting that energy intensive problem areas must be analyzed.

First, regarding energy consumption, the energy consumption percentage of the industrial sector in total domestic consumption has increased since 2000, with an increased rate close to 50%. Increases and decreases are affected by the energy consumption percentage curve of energy intensive industries, of which the chemical materials industry has had increased energy consumption since 1998. Its consumption was increased by 15.36% in 2000, 21.20% in 2001, and 26.17% in 2007. Obviously, the increasing curve of energy consumption also affected energy intensive industries, which energy consumption increased by 35.5% in 2007, and the industrial sector increased by 52.37% in 2007. These findings are close to the changes in increased CO_2 emissions (Fig. 7).

4.2. Energy intensity

Industrial structure problems are more evident upon comparison between the energy consumption of the industries, their contributions to GDP, and the calculation of energy intensity. It can be seen that Taiwan's energy intensity is high in past years, with the highest point at 10.14 loe/thousand TWD in 2001, which decreased in 2009 to 8.82 loe/thousand TWD. Relatively, the energy intensity of energy intensive industries rose to 82.22 loe/thousand TWD in 2000, and was maintained at 82.75 loe/thousand TWD in 2009. The energy intensity of the steel industry was 37.56 loe/thousand TWD in 2001 and dropped to 27.69 loe/thousand TWD in 2009, which

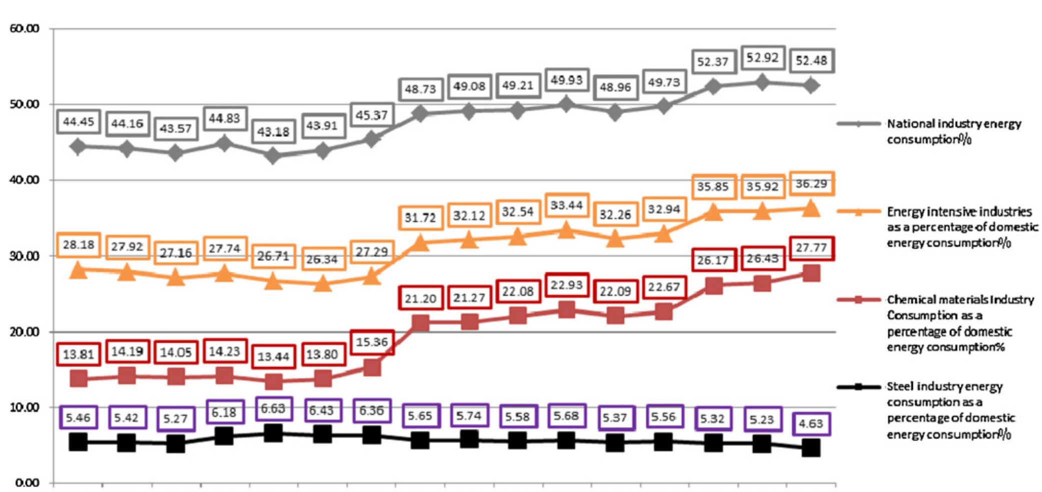


Fig. 7. A graph comparing the energy consumption ratio of energy intensive industries 1994–2009.
Data source: [20]. Compiled by this study. Unit: loe/thousand TWD.

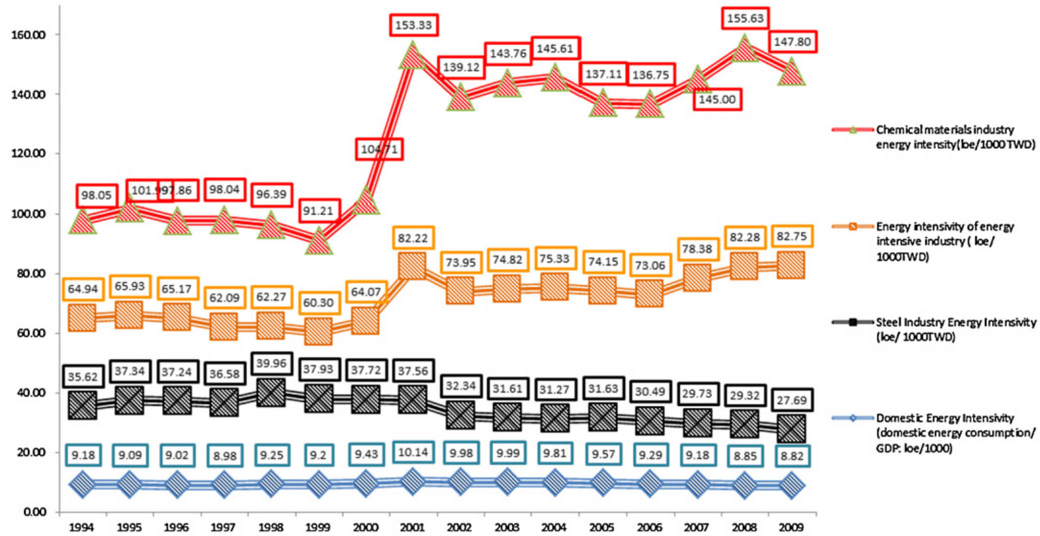


Fig. 8. 1994–2009 energy intensity comparison.

Data source: [20]. Compiled by this study.

was higher than 23.31 loe/thousand TWD and 17.28 loe/thousand TWD of the same year in the industrial sector (Fig. 8).

In particular, the energy intensity of the chemical materials industry was 98.05 loe/thousand TWD in 1994, which is 10 times the domestic energy intensity. It climbed to 91.21 loe/thousand TWD in 1999 and 153.33 loe/thousand TWD in 2001, which is 15 times the domestic energy intensity; and was maintained at 147.80 loe/thousand TWD in 2009, 16.7 times the domestic energy intensity. Similarly, the curve change also affects energy intensive industries and the development of domestic energy intensity.

4.3. Energy consumption and contribution to GDP

Based on the high energy consumption and intensity of the energy intensive industries, their contribution to GDP is further discussed.

4.3.1. Energy intensive industries

Energy intensive industries consumed 30% of the national energy in 2001, followed by rising in each following year, with energy consumption up to 36.29% in 2009 (Fig. 9). During this period, industrial investment continued to advance high energy consuming industries, resulting in increased energy consumption. Intense observations show that the energy intensive industries' contribution to the GDP is not increased with the increased energy consumption [21]. On the contrary, such contribution showed a downtrend, as their contributions accounted for 3.91% of the GDP in 2001, and then increased to 4.33% in 2002 with increased energy consumption; however, it was decreased from 2005, and reduced to 3.86% in 2008 and 2009. It is obvious that the contribution to the GDP did not increase with increased energy consumption.

In addition to increased investment toward energy intensive industries, the percentage trend displays poor energy efficiency, which caused an increased energy consumption percentage by

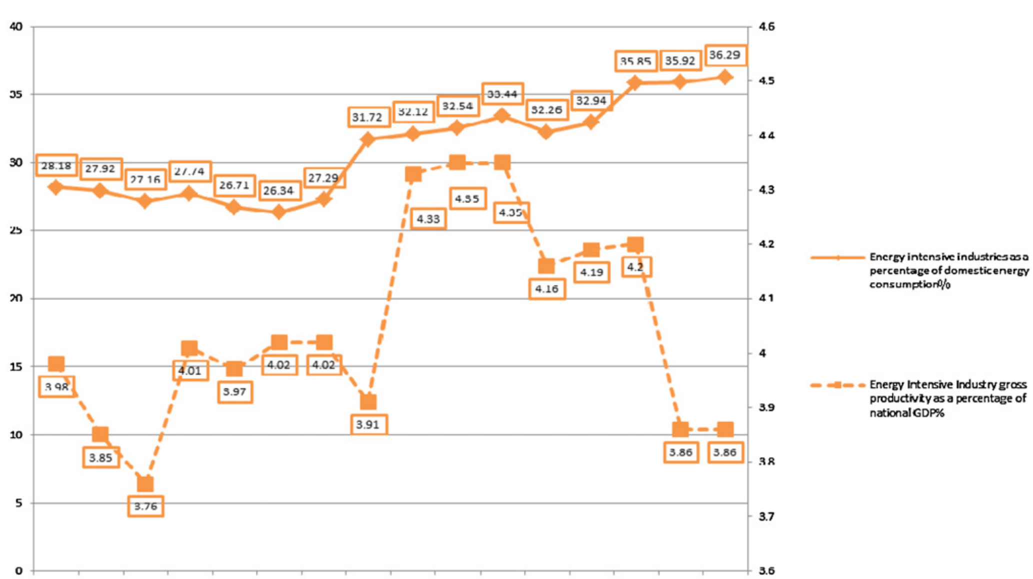


Fig. 9. Comparison between energy consumption and GDP contribution of energy intensive industries in 1994–2009.

Data source: [20]. Compiled by this study.

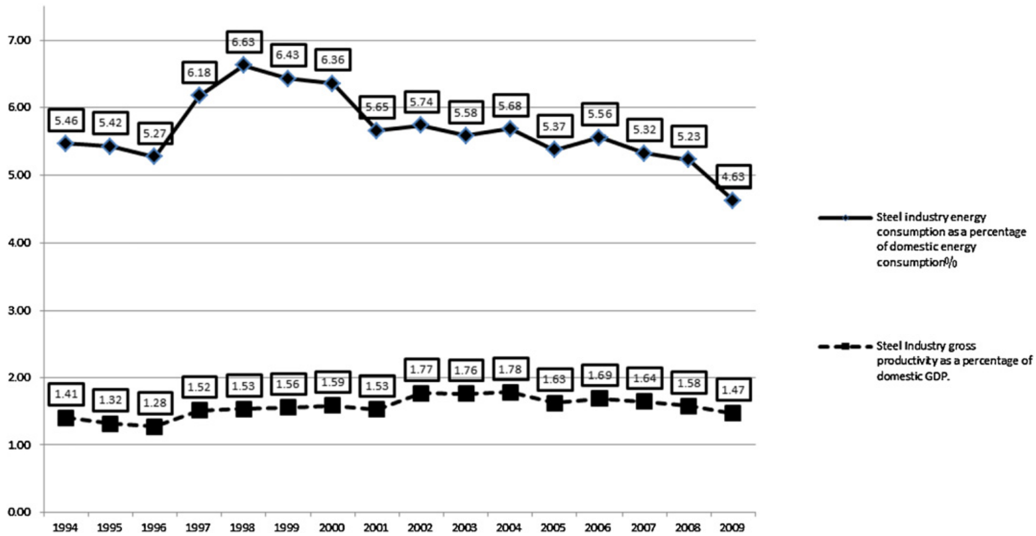


Fig. 10. 1994–2009 steel industry energy consumption and relative contribution to GDP.

Data source: [20]. Compiled by this study.

industries in national consumption, but with lower contributions to the GDP.

4.3.2. Steel industry

In observations of the steel industry, it can be seen that, its energy consumption was increased to 5.27% of the total domestic consumption in 1996 and 6.63% in 1998, reaching its highest point. Afterwards, consumption was decreased yearly, and was reduced to 4.63% in 2009 (Fig. 10). Relatively, its contribution to the GDP is not matched by energy consumption, as it only accounted for 1.77% of the GDP in 2002, which was decreased to 1.47% in 2009. Such development reveals an imbalance between energy consumption and economic efficiency.

4.3.3. Chemical materials industry

In comparison to the steel industry, the chemical materials industry is the main energy intensive industry and its energy consumption percentage is very high. Similarly, its contribution to the GDP cannot compare with its energy consumption; moreover, its corresponding percentage gap is much larger than that of the steel industry (Fig. 11). As compared to Fig. 10, the energy consumption percentage of the chemical materials industry of different years is several times that of the steel industry. However, its contribution to the GDP did not exceed that of the steel industry, as only in 2007 and 2009 was the former slightly higher than the latter.

It is worthy of observation that, the energy consumption percentage was increased from 15.36% in 2000 to 21.20% in 2001, while the contribution to the GDP only rose slightly, from 1.38% to 1.40%. Likewise, its energy consumption rose to 26.17% and continued to gradually increase. Though its contribution to the GDP was increased to 1.66% as compared to the previous year, it dropped steeply to 1.50% in 2008; while the contribution to the GDP was restored to 1.66% in 2009, but cannot increase the energy consumption to 27.77%. Simply speaking, energy consumption and contributions to the GDP by the chemical materials industry is out of proportion, as shown in the energy intensity analysis of Fig. 8.

4.4. Comparison of the contribution percentile to the GDP in energy intensive industries

A comparison of contribution percent to GDP by industrial sectors, energy intensive industries, the steel industry, and the

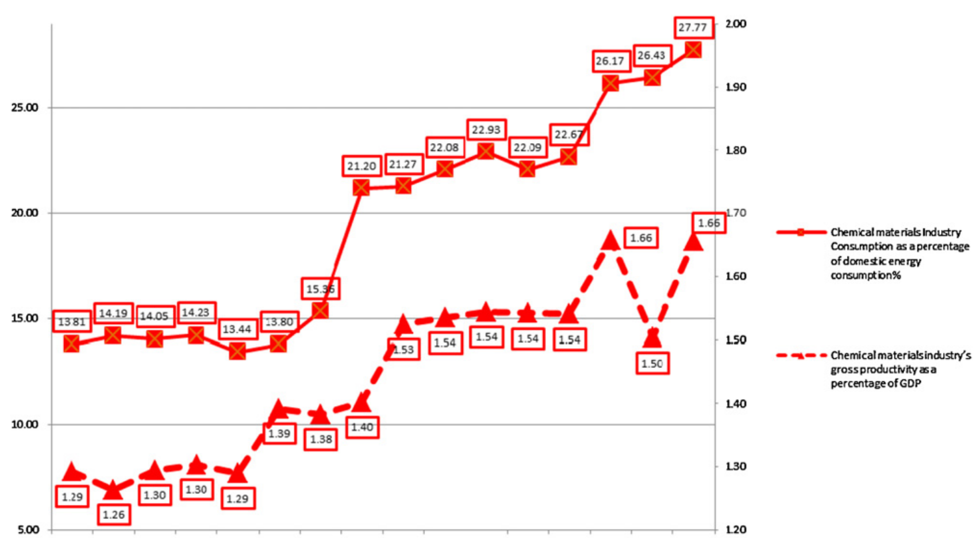


Fig. 11. 1994–2009 chemical materials industry energy consumption and relative contribution to GDP.

Data source: [20]. Compiled by this study.

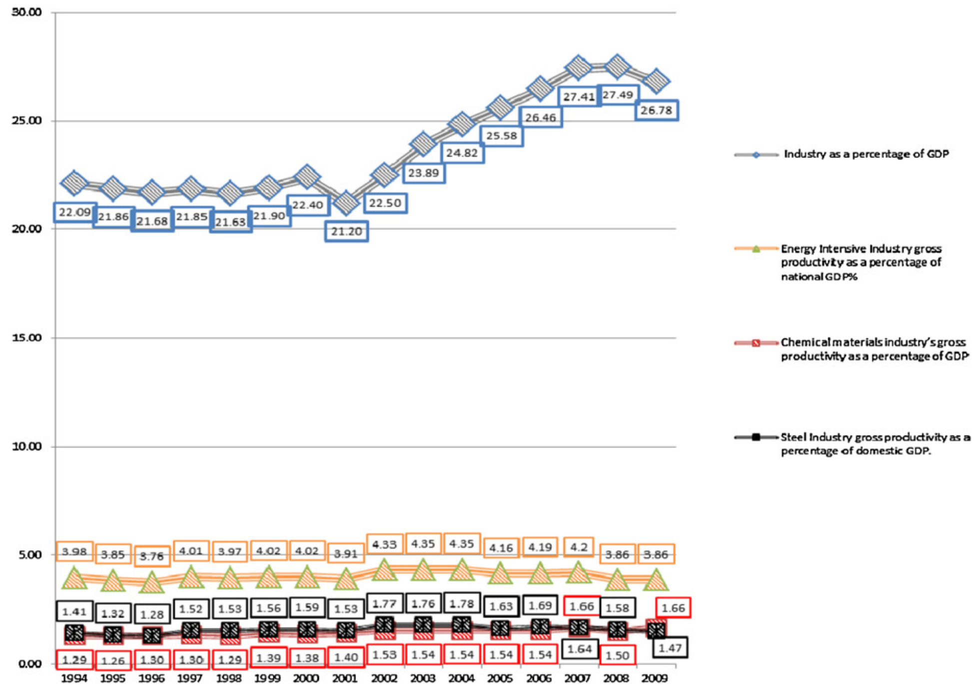


Fig. 12. 1994–2009 contribution of energy intensive industry to the GDP.

Data source: [20]. Compiled by this study.

chemical materials industry is conducted (Fig. 12). First, it was found that the industry sector accounted for only one fourth of the total GDP in previous years, and especially since 2004. Second, the industry sector was not fully affected by its contribution percentage to the GDP of such energy intensive industries. Third, the contribution percent to the GDP of energy intensive industries was not high.

According to comprehensive discussions, the energy consumption of the chemical materials industry was increased from 15.36% in 2000 to 21.20% in 2001. The contribution percent to the GDP was increased from 1.38% to 1.40%. However, the industry sector's contribution to the GDP was decreased from 2001. Between 2002 and 2006 the contribution percentage to the GDP of the chemical materials industry and the energy intensive industries was not developed; to the opposition, the industry sector's contribution percent to the GDP was increased. The contribution percent of both to the GDP was obviously decreased in 2008, while the industry sector continued to present an upward trend. These findings show that, energy intensive industries gradually increased energy consumption percentages; however, their contribution percentages to the total GDP was not high and failed to affect the industry sector's contribution percent to the GDP.

4.5. Summary

The energy consumption percentage of energy intensive industries is high upon observations of energy consumption, energy intensity, and contribution percentage to the GDP in the industry sector, energy intensive industries, chemical materials industry, and the steel industry. Taking 2009 as an example, the energy intensive industries accounted for 69.1% of the total energy consumption of the industrial sector; in particular, the energy consumption of the chemical materials industry, which accounted for 76.5% of the energy consumption of all energy intensive industries and 52.9% of the energy consumption of the entire industrial sector. This trend is very evident in the energy intensity. The domestic energy intensity was 8.82 loe/thousand TWD in 2009, the entire industrial sector's energy intensity was 17.28 loe/thousand TWD, energy intensive industries had 9.4 times the domestic energy intensity and 4.8 times the industrial sector's energy intensity; while the chemical materials industry had 16.7 times the domestic energy intensity and 8.6 times the industrial sector's energy intensity. The contribution to the total GDP in energy intensive industries and chemical materials industry lagged far behind that of the industry sector.

This section presents a high imbalance between energy consumption and contribution percentage to the GDP in these industries. These phenomena indicate that, both industry structure and energy efficiency should be improved, and are directly involved in the policies of climate changes.

5. Conflicts between policies of climate changes and energy intensive industries

5.1. Comparison between industrial output value and CO_2 emissions

Some energy intensive industries are engaged in upstream production and provide important raw materials for midstream and downstream industries, and as such, they have total added value. Therefore, it is necessary to further analyze their contribution to the total industrial output and social cost. A comparison between their percentile in total output value and CO_2 emissions is made in order to discuss efficiency.

In the above energy intensive industries, except for the steel industry, the chemical materials industry (petrochemical industry) is an upstream materials production system, which provides raw materials for midstream and downstream chemical industries, namely, chemical materials industries, plastic products industries, and rubber products industries. Thus, it is the same as the steel industry and requires further analysis regarding the chemical industry's percentile in total output value and CO_2 emissions.

Based upon the statistical analysis of the Energy Resources Bureau, the chemical industries of the industrial sector had the largest CO_2 emissions between 1990 and 2009, with its CO_2

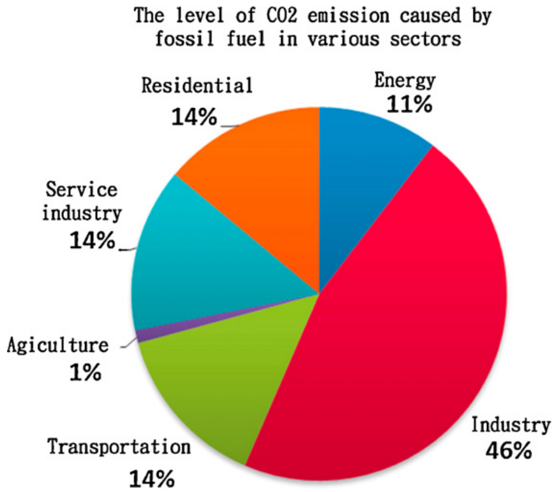


Fig. 13. Taiwan 2009 fossil fuel CO_2 emission sector ratio (various sectors share the burden of electricity consumption).
Data source: [22]. Compiled by this study.

emissions curve increasing from 1997, in particular, during the periods between 1997–2000, 2000–2004, and 2004–2007, and affected the total CO_2 emissions rate (Fig. 4). Based upon industrial output, as disclosed by the Accounting and Statistics Department, the output value of the steel industry and the chemical industry were also increased.[2] However, the output value was lower after the main industrial output was deduced according to operational costs. After the original output of the chemical and steel industries is deducted, according to reasonable energy prices or environmental costs, their contribution percentile to the total GDP is lower than the presented value.

Taking the period of 2008–2009 as an example, total efficiency and social costs can be analyzed using the main industrial CO_2 emissions and individual output values. According to the annual report by the Bureau of Energy [22], the total CO_2 emissions of fuel energy in Taiwan was 255 million tons in 2008, while profits from the industrial sector accounted for only one fourth of the total GDP, yet it produced 48% of all CO_2 emissions. Moreover, regarding the industrial sector's total CO_2 emissions, the chemical industry accounted for 36%, though it only accounted for 19% of the industrial sector's output value; the steel industry accounted for 15% of the CO_2 emissions, while it was responsible for only 13% of the overall output of the industry. In 2009, the total CO_2 emissions of Taiwan's energy fuel was 239.60 million tons, while profits from the industry sector accounted for only one fourth of the total GDP and it produced 46% of all CO_2 emissions (Fig. 13). Moreover, regarding the industrial sector's total CO_2 emissions, the chemical industry accounted for 37%, though it only accounted for 19% of the industry sector's output value; the steel industry accounted for 14% of CO_2 emissions, but was responsible for only 11% of the overall output value (Fig. 14).

These findings indicate that, the main industries with high energy consumption in Taiwan are the steel and chemical industries, which CO_2 emissions exceed half of the industrial sector's total CO_2 emissions; nevertheless, their percentage of total output value was relatively lower, which causes a large imbalance.

5.2. Industry policy adjustment under the climate change policy

From the last section, it can be inferred that, upstream energy intensive industries spread to main midstream and downstream industries, where it can be seen that their percentage of the total CO_2 emissions and output values are not balanced. This phenomenon is concentrated in chemical industries derived from upstream petrochemical industries (chemical material manufacturing). Simultaneously, the cement industry and textile industry were responsible for 5% of the industrial sector's CO_2 emissions, and accounted for only 1% and 2%, respectively, of the total output value. The electrical machine industry accounted for 34% of manufacturing product values and 20% of the industrial sector's CO_2 emissions, suggesting that there remains room for improvement. Overall, the CO_2 emission rates of industrial and manufacturing sectors remains too high, and the percent lacks balance.

According to the statistics of 1980–2009, Taiwan's energy intensity was increased by 2.99% between 1999 and 2003, and decreased by 2% annually during the other periods [23], suggesting that the goal that 2% of energy, as planned to be saved yearly in the 2008 sustainable energy development guideline, is possible. The period of 1999–2003 was an investment period of energy intensive industries.

Based on strategies concerning energy consumption, industry, and carbon reduction under climate change, the service industry, which accounts for 70% of the total GDP, produced 14% of the total CO_2 emissions in 2008 and 2009. Notably, the orientation of Taiwan's economic development requires adjustment. As for energy efficiency, industry planning, and CO_2 emissions source control, it is imperative to adjust industrial investment.

Taiwan's important energy, industrial, and carbon reduction conferences and polices in recent years aim to reduce applications of energy intensive industries, as well as the development of a low carbon economy. In particular, the national industry conferences of 2010 sustained Taiwan's green energy industry, intelligent industry, biomedical, and information industries, which conform to international trends and suggested plans for low-carbon and high-value industries. Therefore, new energy industries, green service sectors, and manufacturing developments are encouraged by the implementation of the Energy Management Act and Renewable Energy Development Act; moreover, the government actively encourages and promotes voluntary greenhouse gas emission reductions and emissions source control through the preparation of the Energy Tax Act (draft) and Green House Gas Reduction Act (draft).

In spite of the perspective policy planning, the Taiwanese government has approved industry investment plans in recent years, and continues to encourage high energy consuming industries, in particular, steel and petrochemical industries with high energy intensity.[3] The actual industrial policies implementations and carbon reduction policies, due to climate changes, have conflicts. On the one hand, energy intensive industries continue to make investments and expand; which increase Taiwan's CO_2 emissions, and fails to conform to research and competition trends of green industries. It is difficult to achieve emission benchmarks for 2020 aimed at reducing 2005 emissions. On the other hand, greater sanction pressures from international green conventions will suffer, and the industries will bear increased trade and manufacturing costs in the future.

[2] The output value of the steel industry was 598,395,000,000 NTW in 1997, 677,594,000,000 NTW in 2000, 1,159,692,000,000 NTW in 2004, 1,631,590,000,000 NTW in 2007 and 1,124,159,000,000 NTW in 2009. The product value of the steel industry was 1,084,030,000,000 NTW in 1997, 1,216,101,000,000 NTW in 2000, 1,867,476,000,000 NTW in 2004, 24,641,210,000,000 NTW in 2007 and 1,989,825,000,000 NTW in 2009.

[3] The disputed Phase V expansion of Taiwan Formosa Plastic Group and Kuokuang Petrochemical Technology will increase 10.58 and 23 million tons CO_2, resulting in increase in total emission.

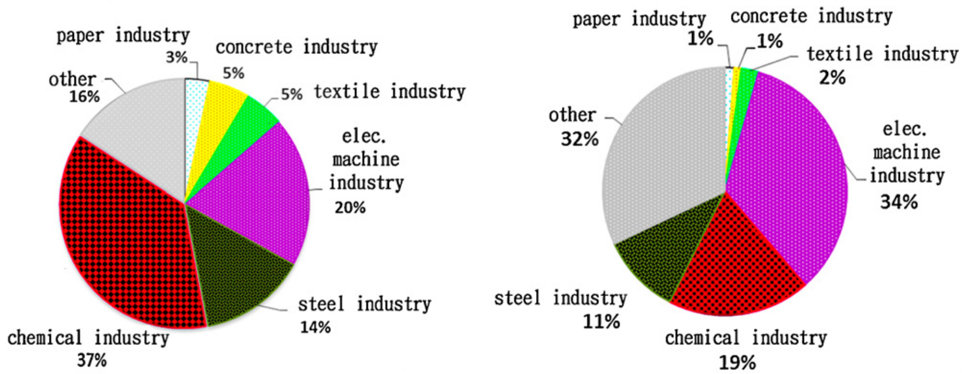


Fig. 14. Greenhouse gas emission by main industries in 2009 and main industries' output value.
Data source: [22]. Compiled by this study.

6. Conclusion

This study proposes the planning and practice for a national sustainable economy and society, as based upon energy, industry, and reduction polices under climate changes, in particular, adjustments to industrial policies. As a newly industrialized country, Taiwan has placed focus on manufacturing and export-oriented economical production and competition models, and is currently in a critical transition period with the gradual development of both foreign and domestic knowledge economies and a service-type society.

According to analysis, the service sector accounts for 70% of the total GDP in the most recent ten years, and has produced only 14% of the total CO_2 emissions; while industrial manufacturing accounted for 1/4 of the total GDP. In recent years, industrial investment has tilted towards industries with high energy consumption, and these industries are responsible for half of the total CO_2 emissions. Taiwan is scarce in natural resources; therefore, the government has vigorously promoted renewable resources in recent years; however, over 99% of fossil fuels are still imported from foreign countries every year, which will continue until the development of new renewable resources becomes mature. Most of the imported energy will be transferred to the industrial sector, and CO_2 emissions will continue to increase yearly if industry policies are not adjusted. Indeed, it can be seen that industrial planning, guidance, and adjustments are urgently required, as based on analysis.

For the past decade, industrial policy has been unbalanced. Thus, analysis shows that chemical materials (petrochemical industry) and steel industries remain the primary cause of the increasing total energy consumption. Particularly, during the three periods of 1997–2000, 2000–2004, and 2004–2007, the upstream petrochemical industry drove the chemical industry's energy consumption increment, while the steel industry drove the industrial sector's energy consumption, which further affects total energy consumption increments. In 2007, the energy consumption of the chemical materials industry was increased to 26.17%, causing energy intensive industries to reach 35.5%, and the industrial sector accounted for 52.37% of the total energy consumption.

The situation can be reflected by CO_2 emissions increments. From Fig. 5, it can be seen that, CO_2 increments of the steel industry, in particular, the petrochemical industry, affects the industrial sector's CO_2 emission and total domestic CO_2 emissions trends. CO_2 emissions of the steel industry were increased by 7.4 million tons during the period of 1996–2000, and 2.8 million tons during the period of 2000–2007. The emission increment of the petrochemical industry accounted for 71.8% of the chemical industrial emissions increment from 1997 to 2000, 78.8% from 2000 to 2004, and 91.6% from 2004 to 2007; meaning it drove the industrial sector's CO_2 emissions and total domestic CO_2 emissions increments.

The unbalanced percent is high upon a comparison between total energy intensity and the energy intensity of the industrial sector, energy intensive industries, the steel industry, and the petrochemical industry. In 2009, the total energy intensity was 8.82 loe/thousand TWD, the average energy intensity of the industrial sector was 17.28 loe/thousand TWD, and the energy intensity of energy intensive industries was 82.22 loe/thousand TWD. Among them, the steel industry was 27.69 loe/thousand TWD; while the petrochemical industry was 147.80 loe/thousand TWD, which was 16.7 times the total energy intensity.

After comparison, energy consumption levels and contributions to the GDP are disproportionate in energy intensive industries, namely, steel and petrochemical industries. On average, energy intensive industries accounted for 31.72% of the total energy consumption in 2001, and afterwards, the percentage increased gradually to reach 36.29% in 2009; however, the contribution percent to the GDP did not increase accordingly with the increase of energy consumption. The contribution percentage to the GDP was 3.91% in 2001, and rose to 4.35% between 2002 and 2004, then decreased gradually after 2005, and was 3.86% in 2009. Apparently, the industries with high energy consumption had disproportionate contribution percentages to the GDP. The steel industry accounted for 6.36% of the total energy consumption between 1997 and 2000, while the contribution percentage to the GDP accounted for 1.56% of the total GDP; and accounted for 5.4% of the total energy consumption between the end of 2001 and 2009, for 1.6% of the total GDP. The unbalance is obvious in the petrochemical industry, where it accounted for 15.36% of the total energy consumption of 2000, 22% between 2001 and 2006, and 26.5% between 2007 and 2009. However, the contribution percent to the GDP had no obvious change in these periods; 1.38%, 1.54%, and 1.66%, respectively.

After further comparisons of contribution percentages to the GDP of the industrial sector, energy intensive and petrochemical industries had small increases, while the industrial sector accounted for 21.20% of the total GDP in 2001; petrochemical industries and energy intensive industries had no obvious changes between 2002 and 2006; however, the industrial sector had a certain increase in contribution percentage to the total GDP. The two former industry's contribution percentages to the GDP decreased in 2008, while industrial sector's GDP continued to grow and accounted for 27.49% of the total GDP. This phenomenon reflects that, the industrial sector's GDP is not affected by energy intensive industries or the petrochemical industry. Moreover, the primary factor driving the industrial sector does not rely on energy intensive industries. From other viewpoints, energy intensive industries accounted for high percentages in the industrial sector's energy

consumption and CO_2 emissions, while their contribution percentage to the total GDP was not high, and had obvious gaps between the industrial sector's contribution percent to the GDP. Besides other policies that are useful for the industrial sector, adjustments of industrial polices shall not hesitation to conform to climate changes and global green convention pressures.

This study suggests that high energy consumption, high CO_2 emissions, high energy intensity, low contributions to the GDP, low contributions to the industrial sector's product value, and low added value cannot meet the transition requirements of a service-type economy society, as based on analysis of energy intensive industries. Newly industrialized countries rely on manufacturing and foreign trade to drive economy growth, but the resultant energy consumption and high carbon emission structure impedes the overall competitive power of industrial sectors. On the other hand, in order to conform to global green industry trends, reintegration of manufacturing and service sector, and adjustments of economic growth engines have become the new industrial competitive strategy under global climate changes.

In recent years, the Taiwanese government has realized these problems in planning important polices, and suggested development guidelines for low carbon industries with high product values through continuous energy, industry, and low carbon simulation. Such actions give dynamic responses to global climate change talks and attempts to guide Taiwan in the development of a sustainable economy and society. However, these polices must be examined in practice.

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